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| <p>(54) Title: METHOD AND SYSTEM FOR PROVIDING SATELLITE SERVICE THROUGH MULTI-ORBIT CONSTELLATIONS</p> <p>(57) Abstract</p> <p>An improved multi-orbit system and method of providing satellite services is described. The invention contemplates that a constellation in an initial state is augmented with additional satellites and that along with augmenting the constellation, the parameters of one or more of the satellites of the initial state are changed in altitude to improve the efficiency or cost parameters of providing the satellite services.</p> <p style="text-align: center;">BEST AVAILABLE COPY</p> | | |

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METHOD AND SYSTEM FOR PROVIDING SATELLITE SERVICE THROUGH MULTI-ORBIT CONSTELLATIONS

DESCRIPTION

Technical Field

5 The present invention relates to the provision of services via earth orbiting satellites. The present invention is applicable to systems including satellites having low-earth orbits (LEO) with any practical angle of inclination such as polar, equatorial, or sun synchronous.

Background of Invention

10 Recent interest has been generated in providing services to the earth via satellites in what is referred to as Low Earth Orbit (LEO). While satellites can provide a variety of services to earth-based consumers, such as communications and photogrammetry, communications is by far the most popular service. Because the cost of manufacturing and orbiting satellites is considerable, there is a desire to
15 minimize the number and complexity of satellites while nevertheless serving as large a region (including the entire earth) as efficiently as is possible.

 There are a variety of orbital inclinations that can be used, sun synchronous and polar are at least two examples, and there are a variety of different orbits within the classes of sun synchronous and polar, all within the LEO range. In
20 general, a satellite at a higher altitude orbit will exhibit a larger footprint, at any instant, so as to cover more of the earth's surface than a satellite at a lower altitude. Some factors suggest use of satellites in higher orbits (because a smaller number of those satellites will suffice to provide continuous coverage). There are

countervailing reasons for favoring satellites at a lower orbit. These reasons include additional sensitivity resulting in higher margins or larger communication capacity, etc.

5 In addition to these variables, the satellite system designer also faces the fact that typically demand grows as a function of time, i.e. when a market is first opened or a service first offered, the demand in that market may be significantly smaller than the demand which the market will exhibit as it becomes more mature.

10 One technique to match capacity and demand is to initially use a satellite constellation at a relatively high orbit, and as demand increases, to discontinue using the higher altitude orbiting satellites in favor of satellites at a lower orbit altitude with greater capacity.

Summary of Invention

15 The invention improves on what might be the typical response to match capacity and demand by initially employing satellites in a high altitude orbit which satellites are also capable of use, and are later used, at a lower altitude. Thus, as demand increases and additional satellites are orbited at a lower altitude, some or all of the higher altitude satellites can be dropped down to the lower altitude so as to reuse the originally high altitude satellite, to improve the efficiency (and/or reduce cost) of the overall system.

20 There are at least two different ways to integrate new satellites into an existing constellation.

In the LEO regime (actually in any regime other than geosynchronous) it is a given that any satellite will have limited coverage so that the constellation will

ordinarily have several "planes" of satellites, where the satellites in a plane cover, or serve, a swath of the earth's surface. The extant constellation may have been designed with gaps between coverage regions, i.e. gaps between some of the swaths of the earth which are covered. As new satellites are added, they may be added in
5 previously unpopulated planes located in the gaps between earth coverage so as to reduce or eliminate the gaps in coverage. In other words, new satellites may be located in planes and orbits which were not previously occupied.

Alternatively, or in addition, the number of satellites in a plane can be increased. Normally, for any given altitude there is a minimum number of satellites
10 which are required to be uniformly distributed in a plane to provide for continuous coverage. One way to increase the number of satellites in the constellation is to increase the number of satellites in a plane up to that minimum number. Increasing the number of satellites beyond this number is of limited benefit if the satellite orbit is unchanged. Thus, in accordance with the invention the limited number of
15 satellites at a given altitude in a plane, are increased by adding one or more satellites in the plane, at an altitude less than the given altitude, and at the same time, or at a later time, dropping one or more of the extant satellites in the plane from the given altitude to the lower altitude of the newly added satellites.

More generally, given a first number, N_1 of satellites in a first plane, at an
20 altitude A_1 , a group N_2 of satellites are injected into a lower orbit, of altitude A_2 in a different plane. The number of satellites in the different plane at the altitude A_2 to provide continuous coverage is greater than N_2 . A sufficient number of the satellites in the first plane have their orbits altered in altitude and inclination to fill out the different plane. In this way the number of satellites in the constellation is altered.

25 Thus, with respect to one aspect, the invention relates to a method of providing services to the earth comprising the steps of:

injecting at least one satellite into earth orbit with an altitude of A1 and providing the services from said at least one satellite,

thereafter injecting at least one additional satellite into earth orbit with an altitude A2 less than A1, and

5 initiating services to the earth from the additional satellite.

In respect of another aspect the invention comprises a method of providing services via a constellation of earth orbiting satellites comprising the steps of:

distributing a constellation of satellites about the earth in orbits lying in one or more planes, each orbit with an orbital parameter of A1, the satellites in the
10 constellation sharing a common regression rate,

providing services from the constellation of satellites to the earth,

thereafter, injecting at least one additional satellite into an orbit about the earth with an orbital parameter of A2 different from A1, the additional satellite having the same orbital regression rate, and

15 providing services from all of said satellites to the earth.

In an alternative aspect, the invention provides a satellite system for providing services to the earth comprising:

a first group of satellites distributed in one or more first planes with a common orbital parameter of A1, each of the first group of satellites having antenna
20 means supporting both an uplink from an earth terminal and a downlink to an earth

terminal, the satellites of orbital parameter A1 being distributed such that each of the first planes contains satellites spaced to provide continuous coverage to a swath of the earth, and

5 a second group of satellites distributed in one or more second planes having an orbital parameter of A2, different from A1, each of the satellites of the second group having antenna means supporting both an uplink from an earth terminal and a downlink to an earth terminal, the satellites of orbital parameter A2 being distributed such that each of the second planes contains satellites spaced to provide continuous coverage to a swath of the earth.

10 Finally, the constellation may be augmented by injecting at least one additional satellite into a previously unoccupied plane, and adding to the at least one additional satellite by moving one or more extant satellites, in altitude and inclination, so as to bring the one or more extant satellite into the same plane with the at least one additional satellite.

15 **Brief Description of the Drawings**

Fig. 1 is a sketch showing the relative footprints for satellites in orbit at two different altitudes, A1 and A2

20 Figs. 2A-2C show earth tracks and earth footprints from different constellations of satellites; in particular Fig. 2A represents a constellation of 40 satellites distributed as 10 satellites in each of 4 planes, Fig. 2B shows the constellation augmented by the addition of 2 planes of 13 satellites, but at a lower altitude and Fig. 2C shows the constellation of Fig. 2B augmented by the addition of 16 more satellites distributed as one additional plane of 13 satellites plus a

commingling of 3 new satellites plus a repositioning (in altitude) of an entire plane of 10 satellites;

Figs. 3A-3C is are similar to Figs. 2A-2C, except that in the case of Figs. 3A-3C the orbits are polar, and

5 Fig. 4 shows a representation of the cells created by a multi-beam communication satellite and are useful to describe how the antenna pattern of a satellite is modified to control the changes in antenna pattern as a function of altitude.

Detailed Description of Preferred Embodiments

10 Before referring to the drawings in detail, some terms are defined for purposes of clarity.

A satellite is defined to mean a man-made object or vehicle intended to orbit the earth, and includes objects in both geostationary as well as other orbits specifically including low-earth orbiting (LEO) satellites.

15 A communications satellite is a satellite which supports communications equipment such as to enable the forwarding or relay of a communications signal from one terrestrial station to another, either directly or via another communications satellite. Communications satellites may also forward or relay signals from or to non-terrestrial stations such as aircraft or other orbiting objects.

20 A constellation is defined to mean an ensemble or group of satellites arranged in one or more orbits for providing specified coverage to portions or all of the earth. A constellation typically includes multiple rings or planes of satellites

and may have equal numbers of satellites in each plane although this is not essential. In addition, the altitude or radius of one orbit or ring or plane may differ from other orbits, rings or planes.

5 An orbit is a path, defined in terms of altitude above the earth and inclination relative to the earth, in which a satellite is relatively stable. In other words the satellite will tend to maintain the altitude and inclination, although that stability may be maintained partly through the expenditure of energy. Typically a constellation will use several orbits and typically there are several satellites populating an orbit. The term plane refers to the geometric construct occupied by
10 several satellites at a given altitude and inclination. Usually there is only one orbit per plane; although as satellites transit from one altitude to a different altitude there may be satellites in a given plane at different altitudes.

To the extent that the terms "cell" and "antenna beam" are used herein, they are not intended to be limited to any particular mode of generation and include
15 those created by either terrestrial or satellite cellular communications systems and/or combinations.

This invention involves the use of orbiting multi-beam communications satellites in low earth orbit. The art is capable of manufacturing and orbiting multi-beam communications satellites in low earth orbits and providing for station-keeping
20 to insure the orbits are stable. In addition the art is aware of techniques to remotely control the antenna pattern, i.e., to alter or control the number or relationship among a group of beams or cells. As a consequence these techniques will not be described herein. The art is also aware of techniques for providing inter-satellite communications in order to improve the services provided by a constellation of
25 satellites. Therefore this application will not address these details.

Fig. 1 is a schematic which shows an important characteristic of the invention. In particular, Fig. 1 shows the earth relative to two different orbits, orbit A1 and orbit A2. These orbits, for example, could be considered low earth orbits. A satellite injected into the orbit A1 can provide services to the earth within a footprint of size represented by D_1 . The size of the footprint is a function of several parameters, one of which is altitude. The satellite, for example, may be a communications satellite which is capable of relaying communications received from an earth station within the footprint or capable of relaying communications to an earth station within the footprint or both.

On the other hand, if the same or similar satellite is placed in a different orbit A2, with a lower altitude, then such a satellite can provide services to the earth via the smaller footprint represented at D_3 . The footprint D_3 is affected by a number of parameters aside from altitude, however Fig. 1 represents the case where the difference between the footprints D_1 and D_3 is solely a function of altitude. In many cases, there is desire to provide continuous coverage. Continuous coverage means that any point within that swath of the earth covered by satellites in the orbit should always be within the footprint of one or another of the satellites in the orbit. Because of the different sizes of the footprints D_1 or D_3 , it requires more satellites in the orbit A2 to provide continuous coverage than the number of satellites in the orbit A1. As will become clear, however, there are countervailing advantages to the orbit A2 over the orbit A1.

While the footprint D_1 or D_3 is determined, in part, by the altitude of the satellite it is also within the skill in the art to restrict the antenna pattern to some dimension less than the footprint D_1 or D_3 . This technique is useful to increase the power density of the signal or to minimize the angular variation of incidence across the antenna.

It is a feature of the invention, however, that a given satellite, first orbited in the orbit A1, will at some point in the lifetime of the system make a transition to the orbit A2 either in the same or a different plane.

5 Assume that there were a sufficient number N_1 of satellites in the orbit A1 to provide for continuous coverage given the footprint D_1 . If the N_1 satellites then transit to the lower altitude A2, then given the smaller footprint D_3 (which is a consequence of the change in altitude) then the number N_1 of satellites is no longer sufficient for continuous coverage and a larger number, N_2 , of satellites is required for continuous coverage.

10 Figs. 2A-2C represent the coverage provided by a changing constellation of satellites in accordance with the present invention. Fig 2A has two subjects superimposed on a representation of the surface of the earth. One of these subjects is a group of lines which, for some of their extent are parallel or almost parallel to each other. These lines or tracks are the projection on the earth of the changing
15 position of orbiting satellites. Each line or track represents the projected changing positions of satellites in a given orbit; in other words, different tracks represent different orbits although each orbit may be (and usually is) populated by a group of satellites. The second of the subjects is a sequence, for each track, of closed figures. Each closed figure represents the footprint of a different satellite. By
20 inspection, there are no gaps along any track. This means that at the instant represented in the figure, any point along any track was within the footprint of at least one satellite and by extension (since the satellites in an orbit move with substantially the same velocity), at any time, any point along any track will lay within the footprint of one or another satellite. In addition it is clear that there are
25 regions of the earth which are not within any footprint (see for example the Australian continent) and so will not be served by this constellation. In other words, for this constellation the regions which are served are served continuously although

there are other regions which are not served. In a first state, services are provided by four planes of satellites in sun synchronous orbit at an altitude of 1400 kilometers. Each plane includes 10 satellites so that the services are provided by a constellation of 40 satellites. Although there may well be spare satellites placed in orbit as a precaution, the spare satellites are ignored for the purpose of this description. Fig. 2A shows the tracks a, b, c and d of these four different planes of satellites. It will be clear to those skilled in the art that while the 40 satellites provide useful coverage, it is not coverage of the entire earth or even coverage of the entire inhabited portion of the earth. Fig. 2A does show, however, that to the extent a region is served, that service is continuous.

Fig. 2B illustrates the coverage when the constellation of Fig. 2A has been augmented by an additional 26 satellites distributed in two different planes, each plane containing 13 satellites at an altitude of 800 kilometers. Thus, Fig. 2B represents a constellation of 66 satellites in 6 planes, 4 planes are populated with 10 satellites each and two planes are populated with 13 satellites each. Inspection of Fig. 2B shows that the augmented constellation is now capable of serving almost the entire earth in that there are, for the most part no regions which lie outside of a footprint. Thus, comparing Figs. 2A and 2B, 26 additional satellites have been injected into orbit to augment the constellation shown in Fig. 2A so as to bring that constellation into the situation or state represented in Fig. 2B. The tracks on the earth produced by the two additional planes of satellites are represented in Fig. 2B by the tracks e and f. Whereas all satellites of the constellation of Fig. 2A orbited at a common altitude, that is not true of the constellation of fig. 2B. For that reason, intersatellite communication for satellites in orbit at 800 km is normally limited to other satellites at that altitude. In other words, satellites in the tracks a-d can communicate with each other and satellites in the tracks e-f can communicate with each other but satellites in the tracks a-d cannot normally communicate with satellites in the tracks e-f and vice versa. Finally, Fig. 2C shows a still later

development of the satellite system. In particular, the satellites shown in Fig. 2C are now distributed into seven different planes. These include three of the four original planes, each containing ten satellites, all at the original altitude of 1400 kilometers. In addition, there are now four planes of satellites at 800 kilometers, each plane containing 13 satellites. The two planes which have been added in Fig. 2C over that shown in Fig. 2B are identified as tracks g and h in Fig. 2C. In addition, the track d which is represented in Figs. 2A and 2B is not represented in Fig. 2C because that track has been eliminated.

More particularly, the transition from Fig. 2A to 2B is achieved by orbiting 26 additional satellites distributed in two planes where each plane contains 13 satellites. The two additional planes are populated by satellites at an altitude of 800 kilometers in comparison to the 1400 kilometer altitude of the original set of 40 satellites in the constellation. However, the transition from the condition of Fig. 2B to the condition of Fig. 2C involves injecting 16 additional satellites into an 800 kilometer orbit. Those 16 satellites are distributed as satellites in two planes. These planes obtain an additional 10 satellites which originally were in orbit at 1400 kilometer altitude but are dropped to the 800 kilometer altitude. As was the case with the constellation of Fig. 2B, while the constellation of fig. 2C allows for some intersatellite communication, that communication is limited to satellites at a common altitude. As has been noted the constellation of fig. 2C has satellites at two different altitudes. Satellites in tracks a-c (track d was eliminated) can intercommunicate and satellites in tracks e-h can intercommunicate but satellites in tracks a-c cannot normally communicate with satellites in tracks e-h.

Table I, below shows the altitude of the satellites in the various tracks as well as the figures of drawing in which the tracks appear.

Table I

| | track | Fig | altitude |
|---|-------|-------|----------|
| 5 | a | 2A-2C | 1400 |
| | b | 2A-2C | 1400 |
| | c | 2A-2C | 1400 |
| | d | 2A-2B | 1400 |
| | e | 2B-2C | 800 |
| | f | 2B-2C | 800 |
| | g | 2C | 800 |
| | h | 2C | 800 |

10 As seen in Fig. 2C, there are three planes of satellites at the original 1400 Km orbital altitude. Actually Fig. 2 C is a transitional situation as these 30 satellites will also be redistributed to the 800 Km altitude. For example, adding 9 more satellites will allow for 3 more 800 Km planes of 13 satellites each.

15 Fig. 4 represents the cells created by a multi-beam communication antenna as may be carried aboard a communications satellite as are used in the present invention. With such an antenna the communication capacity of the satellite is broken down into cells which are distributed into "rings". The example illustrated in fig. 4 shows a number of cells distributed in first, second and third rings. The dimensions of the footprint of the satellite on the earth depends on the satellite
20 altitude, the higher the satellite the larger the footprint. As is also well known the elevation of the satellite, relative to any particular location is also a factor in operation, too low an elevation is not practical as local obstructions can interfere with communications.

25 In one embodiment of the invention, one or more "rings" of cells created by the antenna are not usable because they exist at an elevation which is too low (less than 5 degrees) with the satellite at the higher altitude (1400Km). The designation "a" is used in Fig. 4 to identify beams or cells in the first ring, the designation "b" is used to identify beams or cells in the second ring and the designation "c" is used

to identify beams or cells in the third ring. As an example, a satellite used in implementing this invention, at the higher orbital altitude A1 (for example 1400 km), may use an antenna pattern which creates beams or cells identified as "a" and "b", in other words the third ring of the antenna is not used. On the other hand,
5 when the satellite is placed into a different orbit, one with a reduced altitude of A2 (for example 800 km), then the antenna pattern is altered to use or create beams or cells identified, in Fig. 4, as "a", "b" and "c". In other words at the different altitude the antenna pattern is altered to use all three rings. Those skilled in the art will realize that this is only an example and the changes in altitude may be
10 accompanied by changes in non-unity numbers of rings which are used in the antenna pattern. Typically an antenna pattern will create a hundred or more beams or cells in 3-5 rings or more. Changes in altitude may be accompanied by changes in the number of beams or cells or on the order of 50 or more.

Figs 1 and 4 show the footprint of the typical satellite which is part of a
15 constellation in accordance with the invention and a typical antenna pattern. Thus the satellites employed in accordance with the invention are communications satellites and thus carry communication equipment. That communications equipment will support both an uplink from an earth terminal and a downlink to an earth terminal. It should be understood that the uplink and downlink may be, but not
20 necessarily are, part of a single communications circuit. In other words the typical communications satellite may or may not relay communications signals through other communications satellites. In addition it should be understood that the uplink and downlink referred to are representative because typically each satellite supports many uplinks and downlinks. The preceding statements apply to communications
25 satellites regardless of the altitude or orbital parameter.

Figs. 3A-3C illustrate another application of the invention. In this application the inclination of the orbits of the satellites in the constellation is polar.

Fig. 3A shows an initial configuration or state of a constellation which comprises 40 satellites distributed in 4 planes, each plane includes 10 satellites at an altitude of 1400 Km. For reference purposes each of the four planes is represented in Fig. 3A by a different track, labeled a-d, inclusive.

5 As seen in Fig. 3B, the constellation of fig. 3A is augmented by the addition of 26 satellites, distributed in two planes, each including 13 satellites at an altitude of 800 Km. Fig. 3B illustrates the six planes of the augmented constellation, the initial four planes, a-d and two new planes e and f. As will be recognized by those skilled in the art, the constellation of fig. 3A provides for continuous coverage of a
10 portion of the earth, while other portions are not served. On the other hand, the augmented constellation of fig. 3B provides not only continuous coverage of the served region but also provides for full earth coverage.

Fig. 3C illustrates a further augmentation of the constellation. In particular, the constellation now includes 82 satellites (aside from any spares) distributed in 7
15 planes. Three planes (see tracks a-c) each hold 10 satellites at an altitude of 1400 Km and 4 other planes (see tracks e-h) each hold 13 satellites at an altitude of 800 Km. By comparing the track designations, it will be apparent that the three 10 satellite planes (a-c) are three of the four initial planes, while 10 of the satellites from track d have been relocated into the tracks g and/or h.

20 Just as in the case of Fig. 2C, fig. 3C is also a transitional state. Fig. 3C shows three planes of satellites at the original 1400 Km orbital altitude. As in the case of Fig. 2C, these 30 satellites will also be redistributed to the 800 Km altitude. For example, adding 9 more satellites will allow for 3 more 800 Km planes of 13 satellites each.

As a third example of the invention, initially the satellite constellation includes 50 satellites, evenly distributed in 10 planes each, at an orbital altitude of 1400 kilometers. At this altitude, each satellite employs an antenna beam pattern, including 130 cells. The Nadir angle at 15° elevation is 52.37° . The minimum
5 satellite antenna beam width is 3.7° . Each beam or cell covers an area of 200 kilometers in diameter. The 10 planes each provide for sun-synchronous orbits at a 101.43° inclination.

The second state for the system includes 8 planes of satellites each populated with 13 satellites for a total of 104 satellites in use. In this configuration, each
10 satellite uses two additional rings of beams providing a 197 beams or cells. With this geometry the Nadir angle at 15° elevation is 59.12° and the minimum satellite antenna beam width is reduced to 3.22° . A single cell coverage diameter is now reduced from 200 kilometers to 114 km. However, the relative flux density is 5.1 dB greater in this state than in the initial state. The 8 planes for this constellation
15 exhibit sun-synchronous orbits but inclined at 98.6°

Comparing the first and second states of the constellation, the second state has 1.7 more satellites and 1.52 times as many beams. Because of the increased flux density, the relative system capacity is 2.63 more in the second state than in the first. We could, for example, assign 325 MHz as the system capacity for the
20 first state and 854 MHz for the system capacity of the second state yielding the ratio of second state to first state capacity of 2.63.

One of the prices that is paid for the transition from the first to the second state, is the energy required to change the inclination and orbit altitude for 50 satellites. The actual cost (or penalty) for the change in satellite altitude and/or
25 inclination depends on the technology chosen to develop the required forces. The cost is measured in relation to the part of the satellite mass that is required to be

dedicated to developing the necessary forces. In general the cost may be estimated at a few per cent of the satellite mass.

5 While several different embodiments of the invention have been described, those descriptions are merely exemplary. The invention should not be limited expressly or by implication as a consequence of these examples, rather the scope of the invention should be determined from the claims attached hereto.

CLAIMS

What is claimed is:

- 1 1. A method of providing services to the earth comprising the steps
2 of:
 - 3 a) injecting at least one satellite into earth orbit with a altitude of A1 and
4 providing the services from said at least one satellite,
 - 5 b) thereafter, injecting at least one additional satellite into earth orbit with an
6 altitude A2 less than A1, and
 - 7 c) initiating services to the earth from the at least one additional satellite.
- 1 2. The method of claim 1 which includes the further step of reducing the
2 altitude of said at least one satellite from A1 to substantially equal to A2.
- 1 3. The method of claim 2 which includes the further step of altering an
2 antenna use pattern of the at least one satellite in light of the change in altitude and
3 continuing to provide the services from the satellites.
- 1 4. The method of claim 2 where the step of injecting the additional satellite
2 into an orbit at the altitude of A2, injects the satellite into an orbit which is coplanar
3 with the orbit of the at least one satellite.
- 1 5. The method of claim 2 or 3 wherein the satellites have a common
2 architecture.

1 6. The method of claim 1 wherein the step a) comprises

2 a1) injecting a constellation of satellites into a group of orbits, all of altitude
3 A1, so that there are plural satellites in each of plural planes.

1 7. The method of claim 6 which includes the further steps of:

2 d) reducing the altitude of a selected satellite of the constellation from A1 to
3 substantially equal to A2, and
4 the step b) includes:

5 b1) injecting a set of satellites into the plane of the selected satellite at the
6 altitude of A2.

1 8. The method of claim 7 where all the satellites share a common orbital
2 regression rate so that a distribution and relationship of the satellites in the planes is
3 maintained.

1 9. The method of claim 6 wherein the orbits are polar.

1 10. The method of claim 6 wherein the orbits are sun-synchronous.

1 11. A method of providing services via a constellation of earth orbiting
2 satellites comprising the steps of:

3 a) distributing a constellation of satellites about the earth in orbits lying in
4 one or more planes, each orbit with an orbital parameter of A1, the satellites in the
5 constellation sharing a common regression rate,

6 b) providing services from the constellation of satellites to the earth,

7 c) thereafter, injecting at least one additional satellite into an orbit about the
8 earth with an orbital parameter of A2 different from A1, the additional satellite
9 having the same orbital regression rate, and

10 d) providing services from all of said satellites to the earth.

1 12. The method of claim 11 which includes the further step of:

2 e) adjusting the orbit of one or more of said satellites of the constellation to
3 achieve the orbital parameter A2, where the at least one additional satellite and the
4 one or more satellites have a common orbital plane.

1 13. The method of claim 12 wherein said step c) further includes:

2 c1) altering an antenna use pattern of the satellites with adjusted orbit in light
3 of the orbit adjustment.

1 14. The method of claim 12 where A2 is less than A1.

1 15. The method of claim 14 wherein said step c) further includes:

2 altering an antenna use pattern of the satellites with adjusted orbit in light of the
3 orbit adjustment.

1 16. The method of claim 11 wherein the orbits are circular and the orbital
2 parameter is the orbital radius.

1 17. The method of any claims 11-16 wherein each said satellite has a
2 common design.

1 18. The method of claim 11 wherein the orbits are sun-synchronous.

1 19. The method of claim 11 wherein the orbits are polar.

1 20. A satellite system for providing services to the earth comprising:

2 a) a first group of satellites distributed in one or more first planes with a
3 common orbital parameter of A1, each of the first group of satellites having antenna
4 means supporting both an uplink from an earth terminal and a downlink to an earth
5 terminal, the satellites of orbital parameter A1 being distributed such that each of
6 the first planes contains satellites spaced to provide continuous coverage to a swath
7 of the earth, and

8 b) a second group of satellites distributed in one or more second planes
9 having an orbital parameter of A2, different from A1, each of the satellites of the
10 second group having antenna means supporting both an uplink from an earth
11 terminal and a downlink to an earth terminal, the satellites of orbital parameter A2
12 being distributed such that each of the second planes contains satellites spaced to
13 provide continuous coverage to a swath of the earth.

1 21. The system of claim 20 wherein all of the satellites have a common
2 architecture and orbital planes occupied by the second group of satellites do not
3 contain satellites of the first group.

1 22. The system of claim 20 wherein the orbits of the satellites are circular
2 and the orbital parameter is the radius of the orbit.

1 23. The system of claim 20 wherein the orbits are circular, the orbital
2 parameter is the radius of the orbit and A2 is less than A1.

1 24. The system of claim 20 wherein the earth terminals are gateway
2 terminals or fixed terminals or mobile terminals.

1 25. The system of any of claims 20-24 wherein the orbits are sun-
2 synchronous.

1

26. The system of any of claims 20-24 wherein the orbits are polar.

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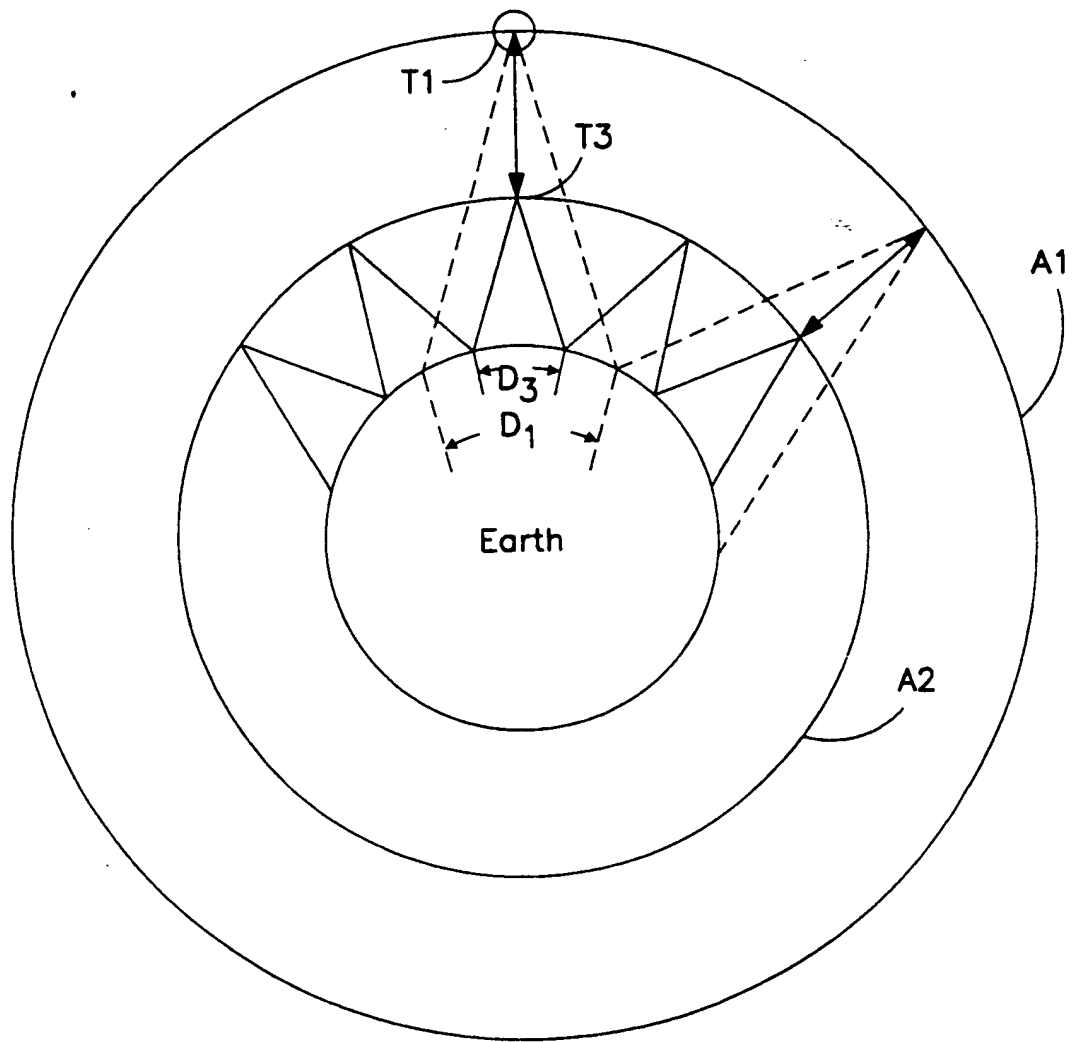


FIG. 1

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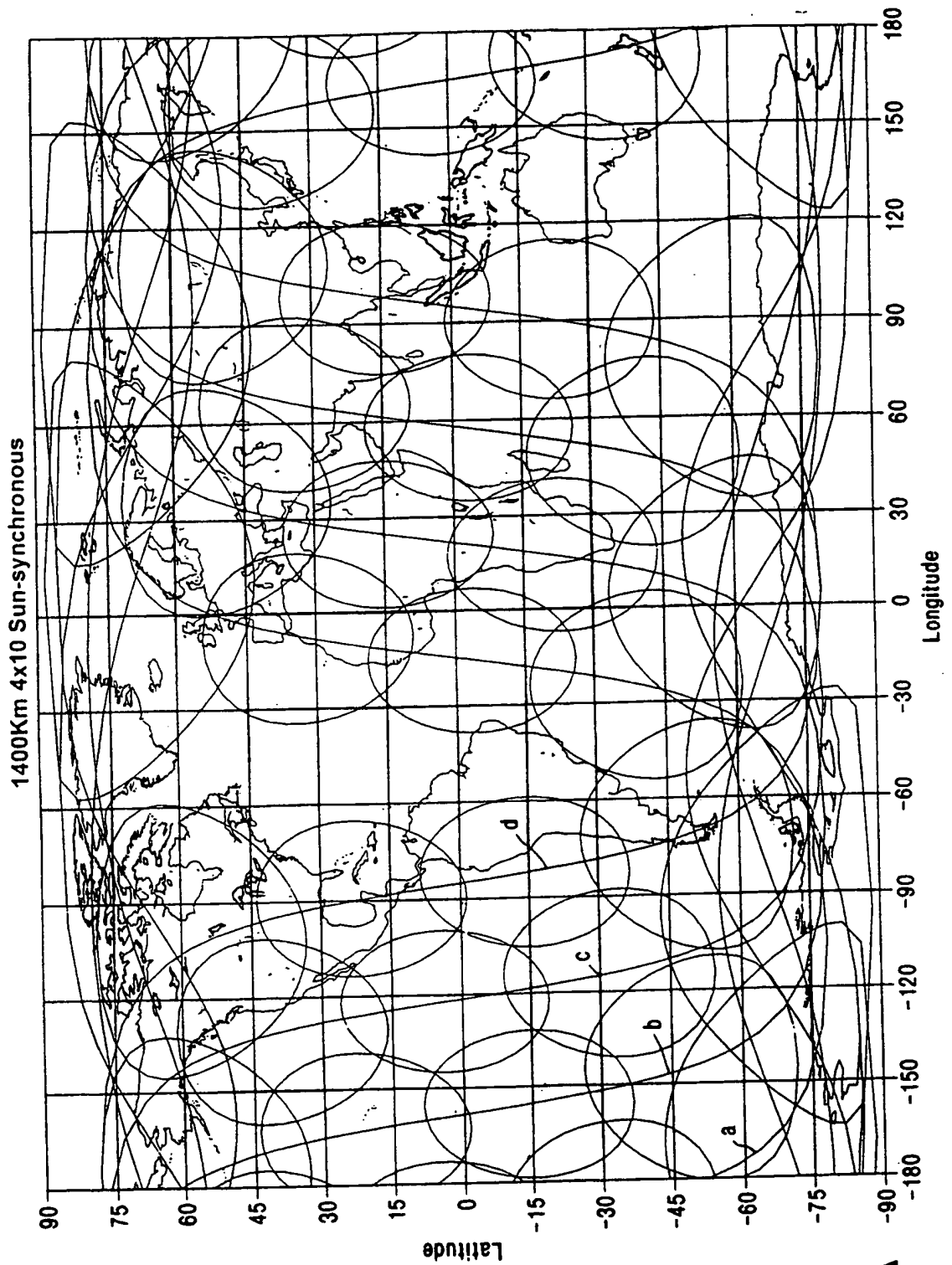


FIG. 2A

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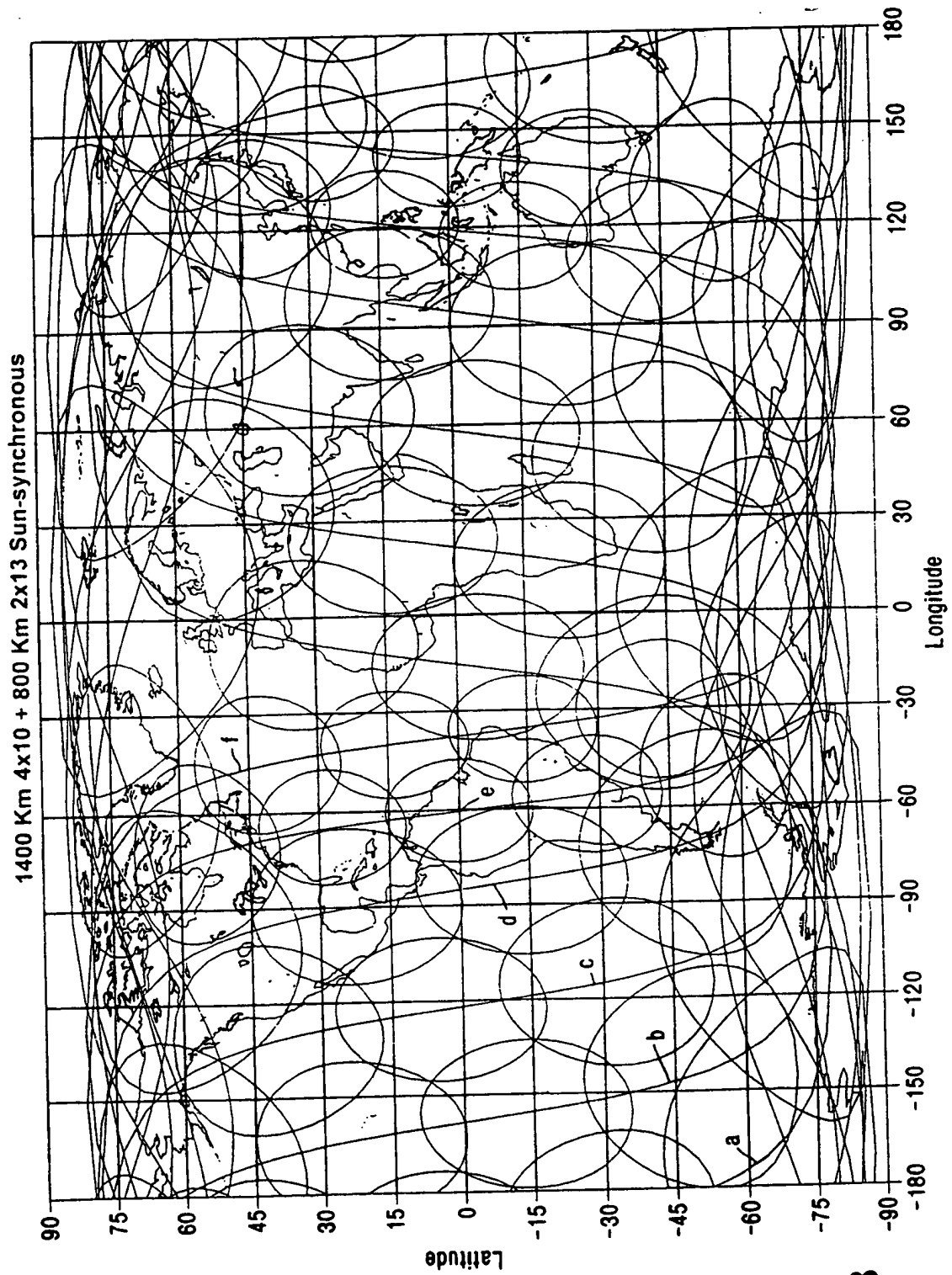


FIG. 2B

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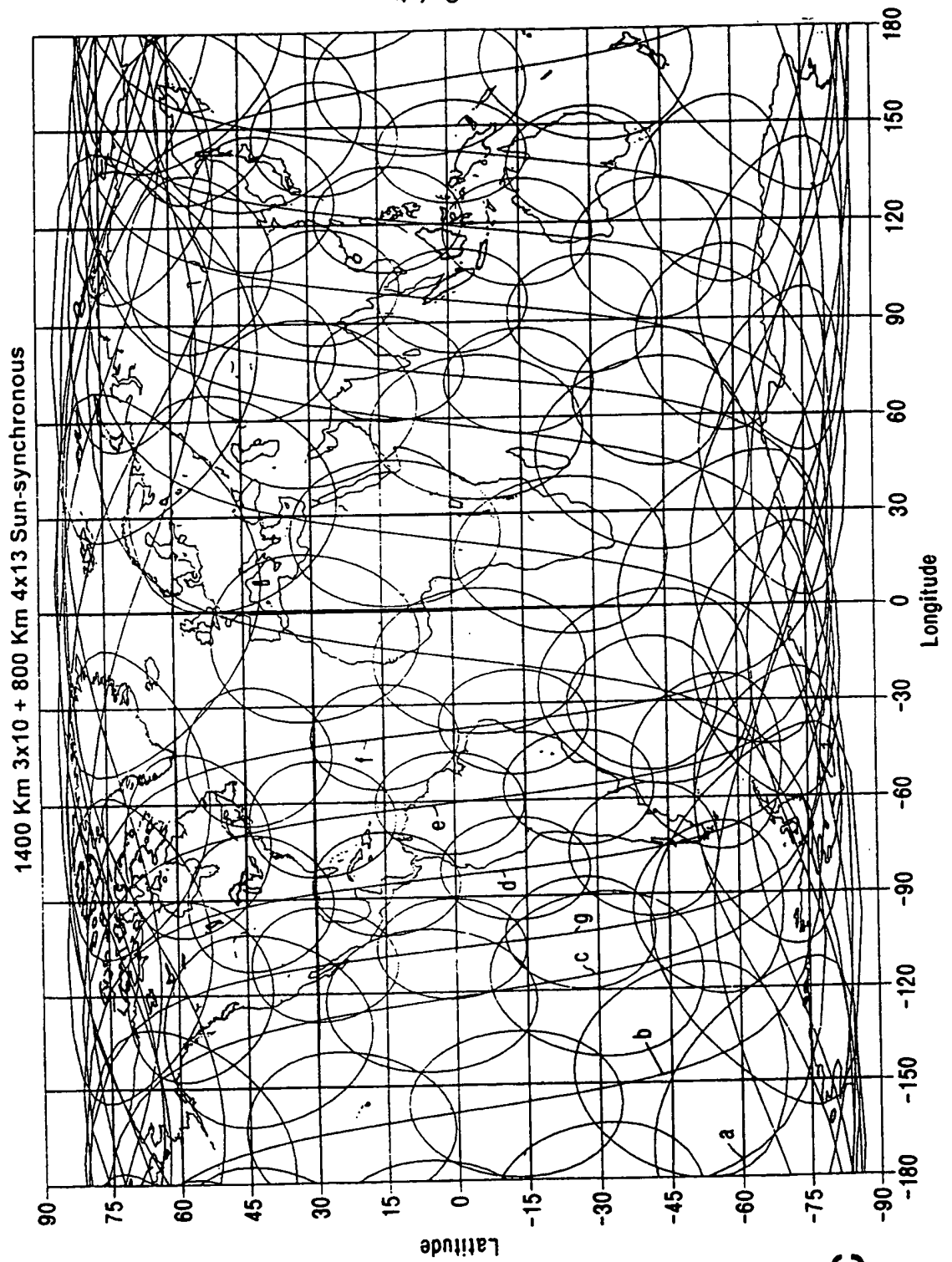


FIG. 2C

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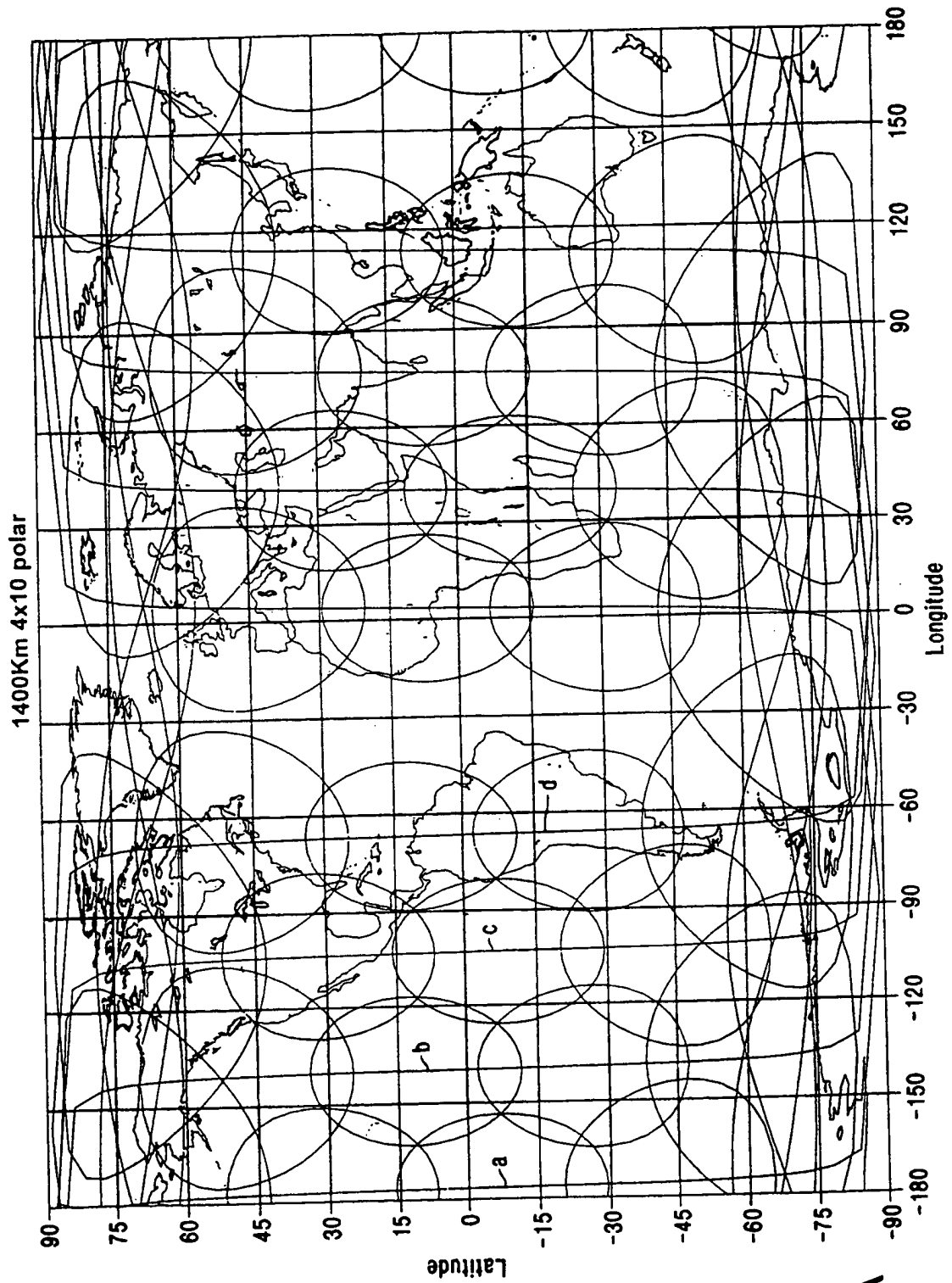


FIG. 3A

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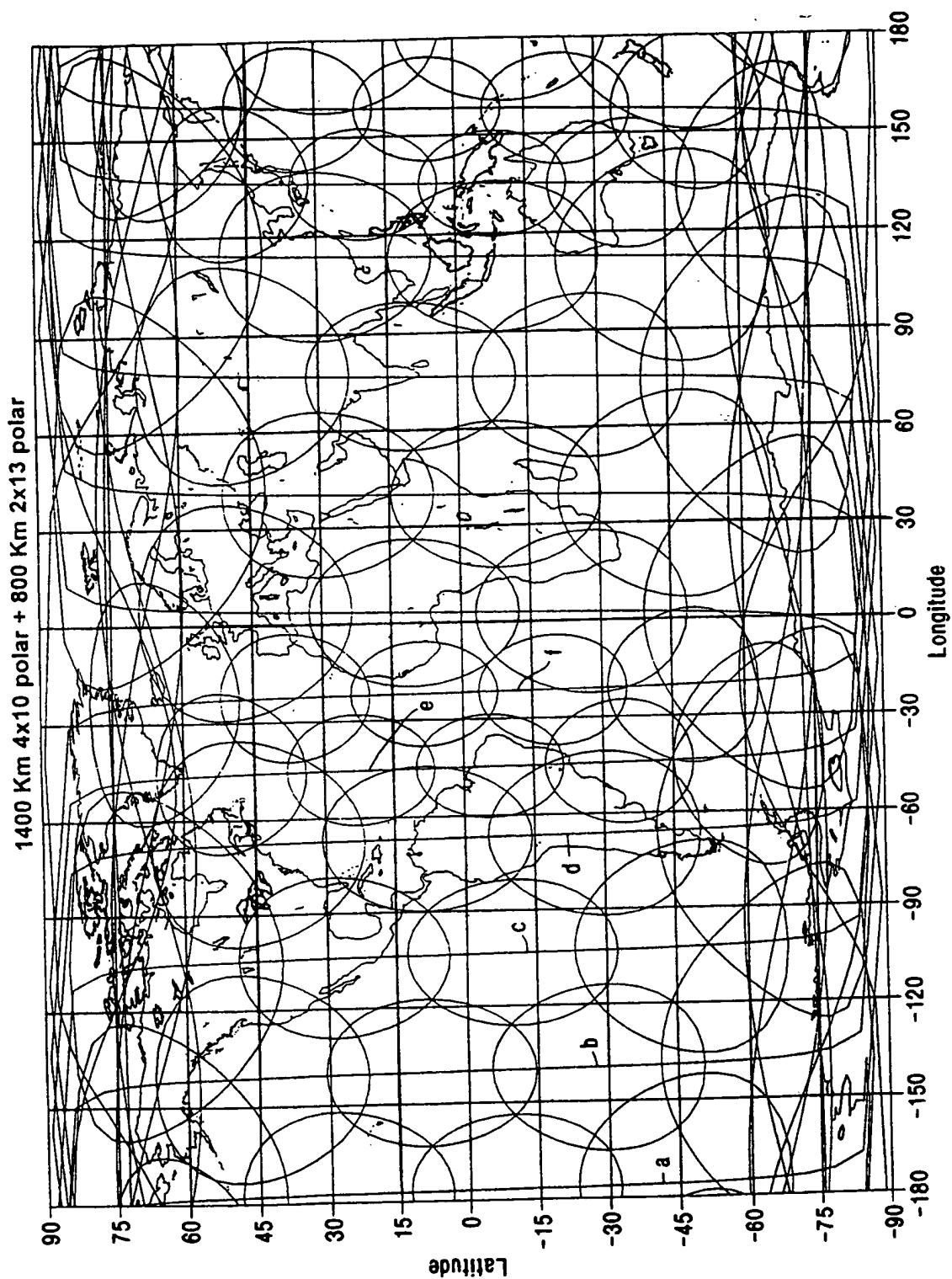


FIG. 3B

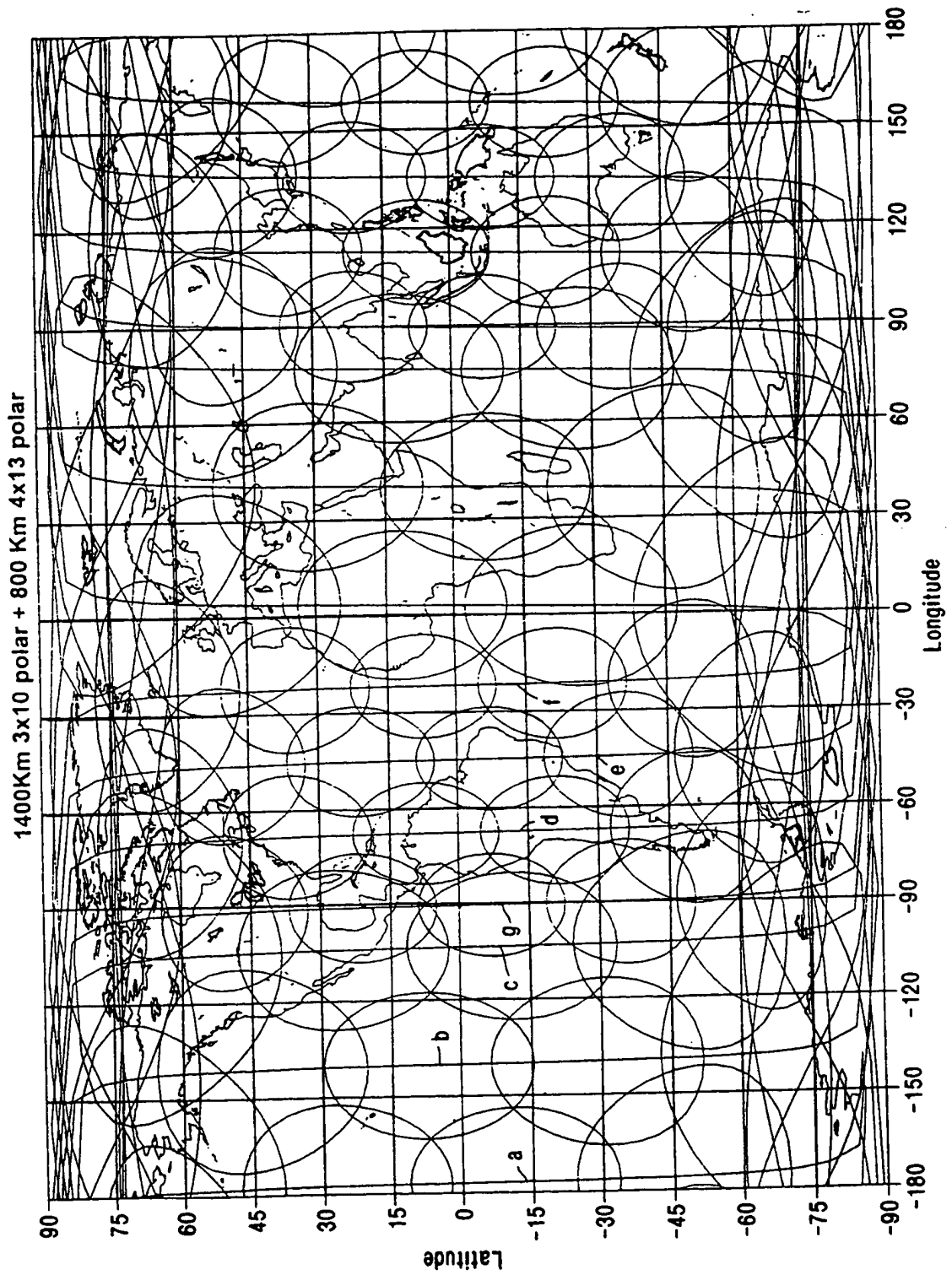


FIG. 3C

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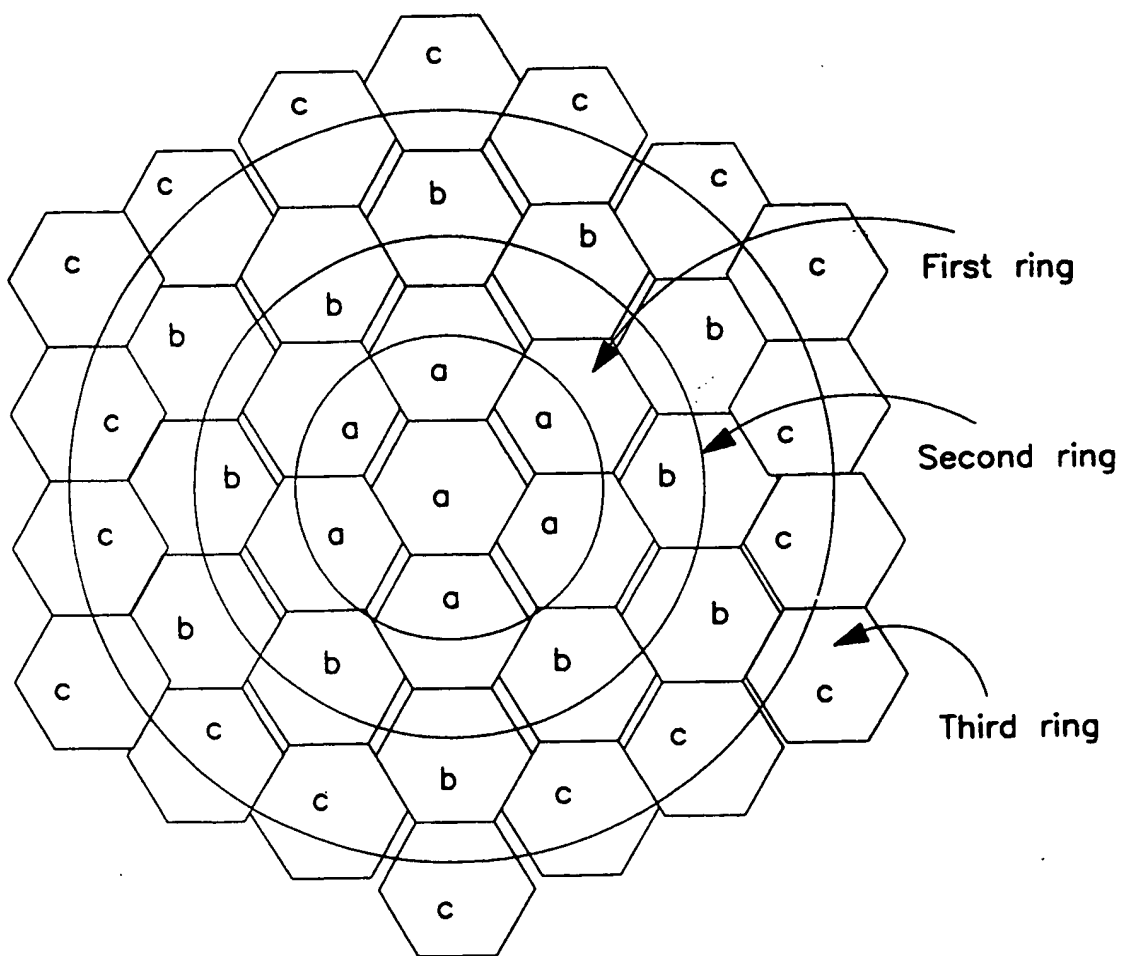


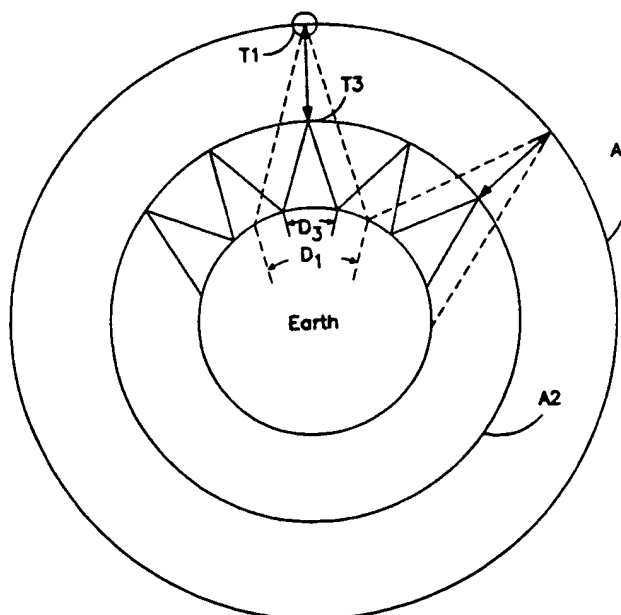
FIG. 4



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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| (71) Applicant (for all designated States except US): IRIDIUM IP LLC [US/US]; 1575 Eye Street, N.W., Washington, DC 20005 (US). | | | |
| (72) Inventors; and (75) Inventors/Applicants (for US only): PODRACZKY, Emeric, I. [US/US]; 7112 Armat Drive, Bethesda, MD 20817-2106 (US). MONDALE, Leo [US/US]; 7309 University Avenue, Glen Echo, MD 20812 (US). | | Published With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments. | |
| (74) Agents: GREEN, Stanley, B. et al.; Pollock, Vande Sande & Amemick, Suite 800, 1990 M Street, N.W., Washington, DC 20036 (US). | | (88) Date of publication of the international search report: 23 March 2000 (23.03.00) | |

(54) Title: METHOD AND SYSTEM FOR PROVIDING SATELLITE SERVICE THROUGH MULTI-ORBIT CONSTELLATIONS



(57) Abstract

An improved multi-orbit system (Fig. 1) and method of providing satellite services is described. The invention contemplates that a constellation in an initial state is augmented with additional satellite orbits (A1, A2) and that along with augmenting the constellation, the parameters of one or more of the satellites of the initial state are changed in altitude to improve the efficiency or cost parameters of providing the satellite services.

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INTERNATIONAL SEARCH REPORT

International application No.
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US CL : 455/12.1

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 455/12.1, 13.1, 13.2, 427, 428, 429; 244/158 R, 159; 342/352, 357

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|--|-----------------------|
| Y | US 5,120,007 A (POCHA et al) 09 June 1992, Fig. 1. | 1-26 |
| Y | US 5,326,054 A (TURNER) 05 July 1994, col. 4, lines 11-19, col. 7, lines 31-39 and col. 8, 3-14. | 1-26 |
| A,E | US 5,927,652 A (LANSARD) 27 July 1999, Fig. 1. | 1-26 |
| A,E | US 5,931,417 A (CASTIEL) 03 August 1999, Fig. 2. | 1-26 |
| Y | US 5,551,624 A (HORSTEIN et al) 03 September 1996, Fig. 1. | 1-26 |

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